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CALIBRATION AND CHARACTERIZATION OF THE WL/MNMF VHG TESTER

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13. ABSTRACT *(Maximum 200 words)*

The WL/MNMF constructed a very high acceleration (vhg) tester to be used in testing a whole fuze or fuze components under a controled severe shock environment. This document present the calibration and the characterization of the vhg tester which were conducted to evaluate the range of application and to quantify the performance of the tester. The calibration defined as the peak acceleration generated as a function of the operating pressure is presented for different payloads. A 100 kg peak acceleration can be achieved even for the largest (10 lb) payload. The introduction of a cardboard mitigator between the piston and the anvil is shown to act as a 20 kHz low-pass mechanical filter. Frequency analysis is used to determine to which extent the vhg tester reproduce shock similar to those encountered in hard target penetration by a kinetic energy penetrator. It is shown that the tester can simulate the hard target penetration environment for the frequency range exceeding 25 kHz.

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PREFACE

This report documents work performed in-house by the Fuzes Branch, Munitions Division, Armament Directorate, Wright Laboratory, during the period from January 95 to September 95. Dr. Alain Béliveau from the Defence Research Establishment Valcartier, Canada and Mr. Eckhard Kuschke from Bundesamt für Wehrtechnik und Beschaffung, Koblenz, Germany were respectively exchange scientist and exchange engineer at the Fuzes Branch. Mr. Timothy Tobik was the program manager.

Captain (CF) Alan Stewart built the vhg tester and his help in the initial phase of the project is acknowledge. Mr. Fred Bath and Mr. Vern Newsom are gratefully acknowledged for providing technical support during testing.

Table of Contents

Calibration and Characterization of the WL/MNMF vhg Tester

1. INTRODUCTION

The testing in the laboratory of specific components under impact conditions requires specialized apparatus able to transmit a high shock to the specimen in a controlled environment. Over the years, many such devices have been built; drop towers, Hopkinson bars, very high accelerations (vhg) testers, etc. Each one has a specific range of application which is limited by the output it can provide (level of acceleration, duration of shock pulse, frequency content, ...) and the size and weight of the specimen it can test. To extend the range of its testing facilities, the Fuzes Branch at the Armament Directory of the Wright Laboratory (WL/MNMF) recently built a vhg tester. This apparatus is able to impart a very high acceleration level to a relatively large mass (up to 10 lb.). The design is similar to the original vhg tester built by the Naval Ordnance Laboratory (Ref. 1).

This brief document describes the operation and the performance of the Fuzes Branch vhg tester. It is intended as a useful tool for the test engineer and a calibration bench for other test designs.

2. DESCRIPTION AND OPERATION

2.1 Description and operating principle

The vhg tester is essentially a short vertical air gun that quickly accelerates a piston which impacts the test carriage holding the test item. This transfer of energy transmits a shock pulse with a high acceleration level and a short duration to the test specimen.

This high acceleration generating device is very compact. It occupies less than 12 square feet of floor space and is about 6 feet high and its total weight reaches 1700 pounds. The principal components of the vhg tester are the low pressure air chamber, the safety shield, the air gun barrel, the test carriage, the stopping mechanism and the control panel. The characteristic and the role of each part will not be detailed here as they have already been presented in the Naval Ordnance Laboratory report [see Ref. 1].

The only source of power required to operate the vhg tester is a low pressure line (up to 100 psi). The operating principle is simple; the 30 pounds piston is locked in place at the bottom of the barrel as the pressure is built up in the pressure chamber, when the proper pressure is reached, a lever activates the release of the piston which is accelerated in the 25 inches barrel. The piston then impacts the test carriage which is located just above the end of the barrel. The test carriage is held in place by an Aluminum yoke and isolated from it by a rubber ring. The Aluminum yoke is attached to two hydraulic pistons that gently slow down the carriage. After releasing the built up pressure in the gun barrel,

the piston returns to the bottom of the barrel on its own weight and so does the test carriage.

2.2 Operating instructions

The operating instructions for evaluating the behavior of a test item under shock are given here as a sequential procedure:

1. Mounting the test item

WARNING

> Before mounting the test item, make sure to vent the air gun by setting the left-hand lever to "vent". Also disconnect the supply air line.

The test carriage has a "cup" shape with and outer diameter of 4.75", an inner diameter of 3.25" and a depth of 2.3". The rim of the test carriage contains eight 3/8-16 tapped holes on a 4" diameter bolt circle. The item to be tested can be mounted inside the cup or on it using a steel plate to cover the "cup".

The shock imparted to the test carriage anvil can be severe enough to fracture low strength bolts. It is recommended to use only high impact strength bolts. The test item should be tightly secure (to the test carriage or to a plate to be fixed on the test carriage). All the eight bolts should be used for the final assembly as this will lessen the chance of bolt fracture and also avoid resonance cause by a loose mount which could corrupt the result and its analysis.

NOTE: These bolts should be tighten after each impact. It is also important to tighten the two bolts used to compress the rubber ring in the Aluminum yoke which sandwich the test carriage. Damage to the yoke can occur if it is not secured properly.

2. Closing the safety shield

The safety shield should be closed after the test item is secured and all the connections made. Make sure to clean the top of the vhg tester before closing the shield. This is important as the gun barrel is always opened and small particles (especially metallic ones) could fall in the barrel, get trapped between the piston and the barrel and scratch the barrel surface.

3. Connecting the air line

The supply air line for the vhg tester is provided by a commercial air compressor. Note that when in operation the compressor is quite noisy. It is recommended to move the compressor out of the room or to wear ear protectors. Before connecting the air line,

set the left-hand lever to "vent" (it should already be in this position) and the right-hand lever to "lock".

4. Arming the vhg tester

Arming is accomplished by pressurizing the low pressure chamber. In the process, the first step is to set the regulator to the desire pressure. Before pressurizing, it is useful to "play" with the "lock/unlock" lever by alternating between those two positions a few times to ensure that the piston is sitting at the bottom. A loud metallic sound should occur as one moves between those two positions.

While the lever is in the lock position, pull the left-hand lever from the "vent" to the "pressurize" position to pressurize the high pressure chamber.

<u>WARNING</u>
Do not reach a pressure exceeding 80 psi.

Use the pressure gage to read the pressure in the chamber (do not rely on the regulator setting). The combination of "pressurize" and "vent" modes facilitate adjusting the pressure to the proper value. A "hold pressure" position is obtained by setting the left-hand lever to the middle position, between the "pressurize" and the "vent" position, then the valve is close. This is the proper setting before firing.

If the desire pressure can not be reached, verify the setting of the regulator and the available pressure in the air compressor.

5. Firing

The piston is released by pulling the right-hand lever from the "lock" to the "unlock" position. Upon impact the test carriage can travel up to 14 inches. Note that a muzzle retaining ring stops the piston from exiting the barrel. Do not operate without this ring as the piston can be ejected out of the barrel even at very low pressure.

6. Releasing the pressure

After the test is terminated, the piston is still under pressure and the left-hand lever must be put into the "vent" position before opening the safety shield. Note that for pressure above 60 psi, venting the air gun will produce a loud high pitch noise and the use of ear protector is highly recommended.

7. Opening the safety shield

The supply air line should be disconnected before opening the shield (the line has a quick-disconnect coupling).

8. Purging the air compressor

The air compressor should be purged at the end of each day. See the manufacturer manual for the proper procedure.

Following these instructions will result in a reliable and safe use of the vhg tester. The performance of the vhg tester and a basic calibration relating the loading pressure and the shock level is the subject of the next chapter.

3. CALIBRATION

The term calibration is used here to specify a relation between the firing pressure in the vhg tester and some physical quantity characterizing the shock pulse transmitted to the test item. Knowledge of the calibration allows a better selection of the operating pressure to obtain the desirable shock level. It also presents a clear picture of the performance of the tester and its limitations.

Two questions come to mind in deciding a proper calibration for the vhg tester: which physical quantity(ies) can best describe the shock imparted to the test item, and which parameters are most useful for characterizing this quantity (peak value, average value, duration, standard deviation, ...).

The foreseen range of application for the vhg tester extends from evaluating sensors and electronic components to testing a whole fuze under shock. At the present time, the preferred physical quantity to characterize a load on a fuze during penetration of a hard target is the acceleration sensed by the warhead and its components. Therefore it was decided that the shock generated by the vhg tester would be described by the acceleration pulse experience by the test component.

The acceleration pulse amplitude and duration are the easiest way to simply define its shape. It is an incomplete description as the pulse may contain many sub-structures. Nonetheless, the peak value and pulse duration were selected to define the calibration of the vhg tester.

It is important to note that the impact of the piston on the test carriage is a metal to metal impact which generate a shock pulse with very high frequency content. Therefore any undamped commercial accelerometer will go into resonance under such a shock and might even be damaged. One can then understand that it could be erroneous to read the peak value from an accelerometer under these severe impact conditions. Such a straight forward reading will not provide in many cases a valid representation of the pulse amplitude transmitted to the test carriage but an artifact from the accelerometer resonance.

It was decided that the raw data would be low-pass filtered to eliminate any effect due to resonance before reading the peak value defining the calibration. The type of filter and the cut-off frequency will be discussed in the following sections.

3.1 Sensor selection, mounting and monitoring

The accelerometers selected to calibrate the vhg tester were all from the Endevco 7270A series. Two types of accelerometer were used each covering a different range of acceleration. They were the model 7270A-200 (which has a range up to 200,000 g_n {1 g_n = 9.8 m/s^2}[i]) and the model 7270A-60 (with a range up to 60,000 g_n). Those are piezoresistive accelerometers and have a very fast response, no damping and a very high resonance frequency (1.2 MHz for the 7270A-200 and 750 kHz for the 7270A-60). They require a 10V power supply and have sensitivity ranging from 0.8 μV/ g_n to 4.0 μV/ g_n.

Each accelerometer was mounted on a 5.5″ diameter cylindrical steel plate which was attached to the test carriage with 3/8-16 bolts. Two different weights were used for the plates: a 5 lb and a 10 lb. These will be referred as the payload because they represent the weight of the test item that can be mounted on the test carriage. The accelerometers were mounted on the plate with two 4/40 screws using a torque of 8 lb-in as specified by the manufacturer. The cable was fixed to the steel plate using tape and leaving a 1/2 inch strain relief.

Powering and monitoring of the accelerometer is a major problem at the present location of the vhg tester (Bay 2 of the WL/MNMF). When the accelerometer is powered by a 10 Volts (DC) power generator and monitored by an oscilloscope, random spikes of great amplitude (up to a few volts) in the signal forbid the use of the scope trigger. Use of mechanical switches to generate the trigger signal permits recording the signal at the proper time but does not eliminate the random spike which will at time corrupt the measured acceleration pulse.

Two approaches were designed to eliminate this problem. In the first approach, the accelerometer is powered from a battery pack and monitored by an oscilloscope. In the second approach, the accelerometer was powered by a DC power generator and monitored by a data acquisition recorder IES model 31 (se Ref. 2). Each option has its advantages and disadvantages; in the first approach, constant monitoring of the batteries voltage is required as the output of the accelerometer is a linear function of the input voltage which decreases as the batteries become drained. One advantage of using the scope is that the sampling frequency can be made high enough (≤ 2.5 MHz) to observe

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[i] The symbol for the free fall acceleration on the earth is "g_n" and not "g" which stand for gram (the mass unit of the International System of Units). Similarly, kg_n is a thousand time the gravitational acceleration while kg represent the unit of kilogram.

the resonance of the 200 kg_n accelerometer[ii]. When using the recorder to acquire the data, a constant power can be used but a mechanical switch is required to trigger the recorder and the sampling frequency is fixed at 1 MHz which prevent monitoring of the resonance mode of either accelerometer used.

3.2 Peak acceleration vs. pressure

As mentioned in the introductory section of Chapter 3, the peak acceleration vs pressure calibration curve for the vhg tester should not be taken directly from the accelerometer raw data because resonance in this device will bias the result; the raw data must be filtered to eliminate this effect. To conserve most of the high frequency of the shock signal in the calibration of the vhg tester, a high frequency of 100 kHz was selected as the cut-off frequency for the filtering of the data. This frequency is sufficiently far from the resonance to eliminate its effect and high enough to be useful in determining the high frequency content of the shock.

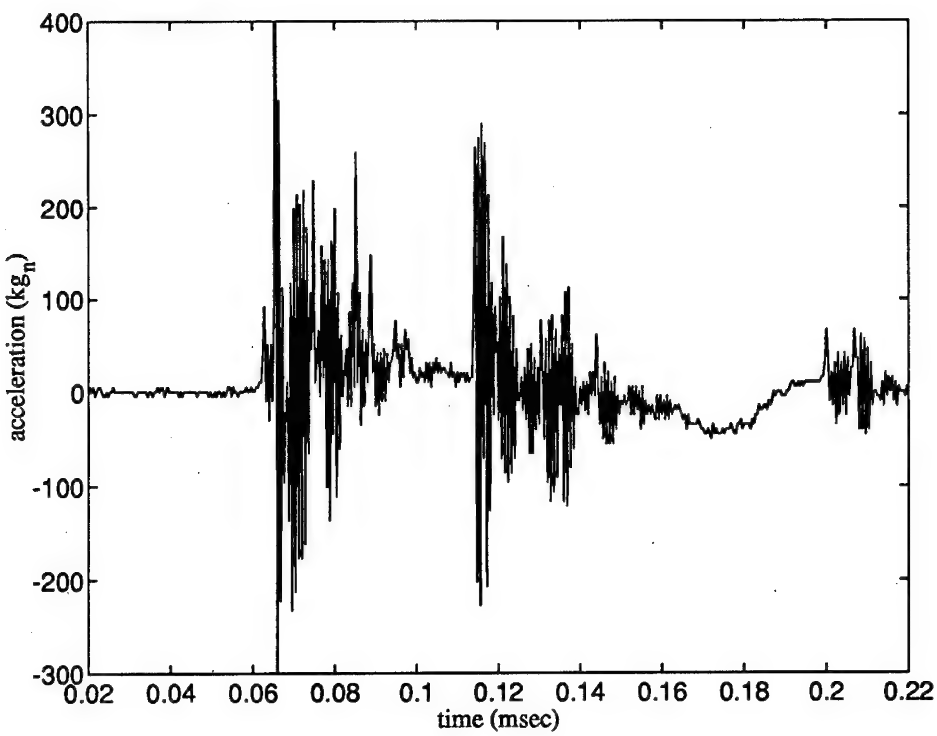

Figure 1. Acceleration pulse measured by the accelerometer. The effect of the accelerometer resonance is seen.

[ii] It is useful to monitor the resonance mode of these accelerometer for it is a precursor of eminent damage to the sensing device.

All the data were numerically passed through a 4-pole Butterworth 100 kHz low-pass filter before measuring the peak acceleration of the shock pulse. The raw data showing the strong effect of the resonance is depicted in Figure 1. For the same case, Figure 2 shows the filtered data and the more reliable peak acceleration value.

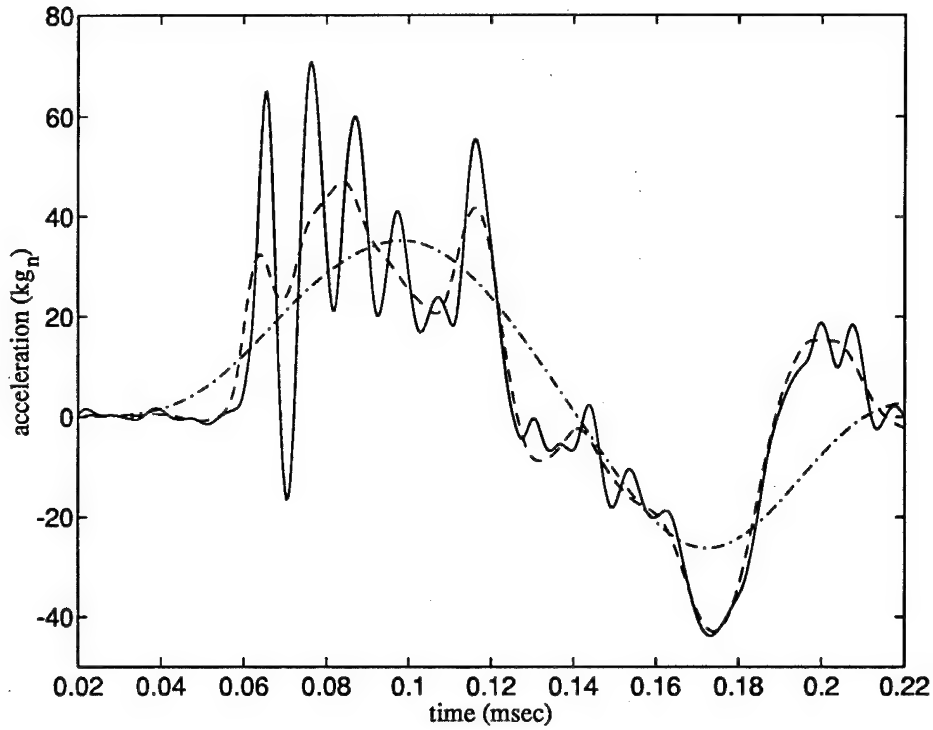

Figure 2. Same results as in Fig. 1 but low-pass filtered at different cut-off frequencies (fc). Continuous line; fc = 100 kHz, broken line; fc = 50 kHz, dot-dash line; fc = 10 kHz.

3.2.1 Calibration for a 10 lb payload and no mitigator

In this series of tests, a 10 lb steel cylinder was attached to the test carriage and an accelerometer was fixed directly on top of the cylinder. No mitigator was placed between the impacting piston and the anvil, therefore metal on metal impact was recorded which yield a shock pulse with a high frequency content. These "metal-on-metal" impacts are likely to damage the accelerometer by exciting its resonance mode. It is therefore very important to carefully monitor the high frequency amplitude and to stop testing if the peak acceleration reaches the overrange limits specified by the manufacturer.

Figure 3 displays the results of the peak acceleration of the processed data (low-pass filtered to 100 kHz) for all the tests performed. A quadratic fit is also displayed to guide the eyes in selecting the appropriate pressure for a desired peak acceleration. Note that the dispersion for a given pressure is important. Various factors can affect the performance of the vhg tester; friction of the piston in the barrel, variation in the pressure due to the crude scale on the pressure gage, gas leak, etc. These have not been assessed and evaluated.

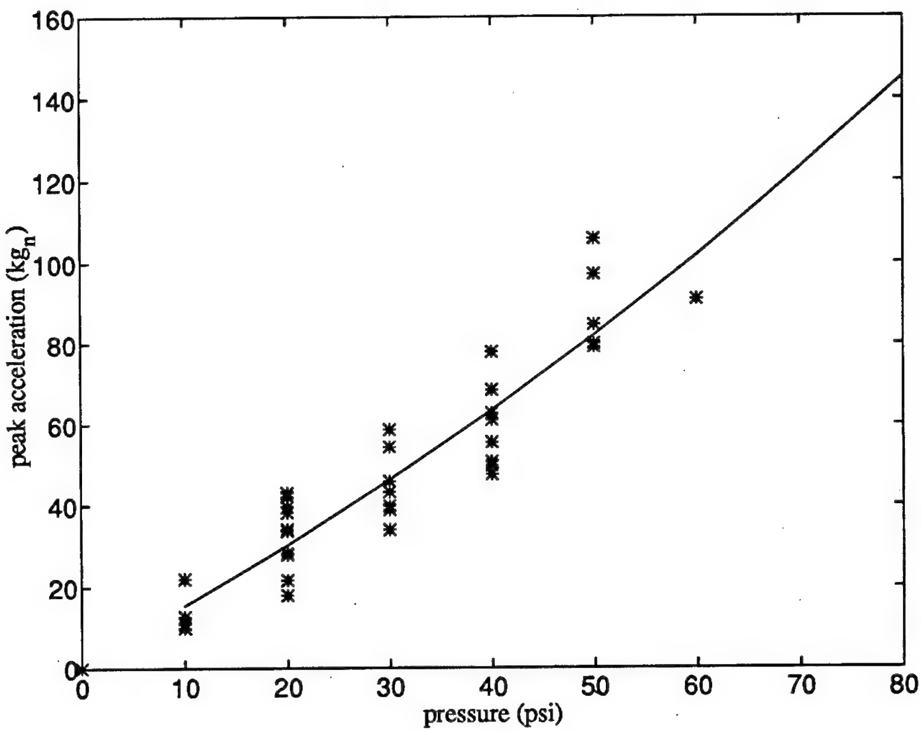

Figure 3. Peak acceleration of the 100 kHz low-pass filtered shock pulse versus the operating pressure of the vhg tester. A 10 lb payload was used and no mitigator was installed. The straight line is a quadratic fit to the data and is extrapolated to the maximal operating pressure.

No test was performed above 60 psi and only one was performed at 60 psi. Though the vhg tester can be pressurized up to 80 psi, the ringing was so intense at 60 psi that permanent damage to the sensor was expected to occurred if the shock was increased. To obtain data above this range, the accelerometer would have to be mechanically filtered to eliminated the high frequencies or a different sensor should be used. At this time, no effort has been taken in this direction.

3.2.2 Calibration for a 5 lb payload and no mitigator

A series of tests similar to the one described in the previous sub-section was performed with a 5 lb payload. Of course a higher acceleration vs pressure calibration curve was measured. The difference between the peak accelerations for the two payloads can be roughly evaluated at 20% as observed in Fig. 4.

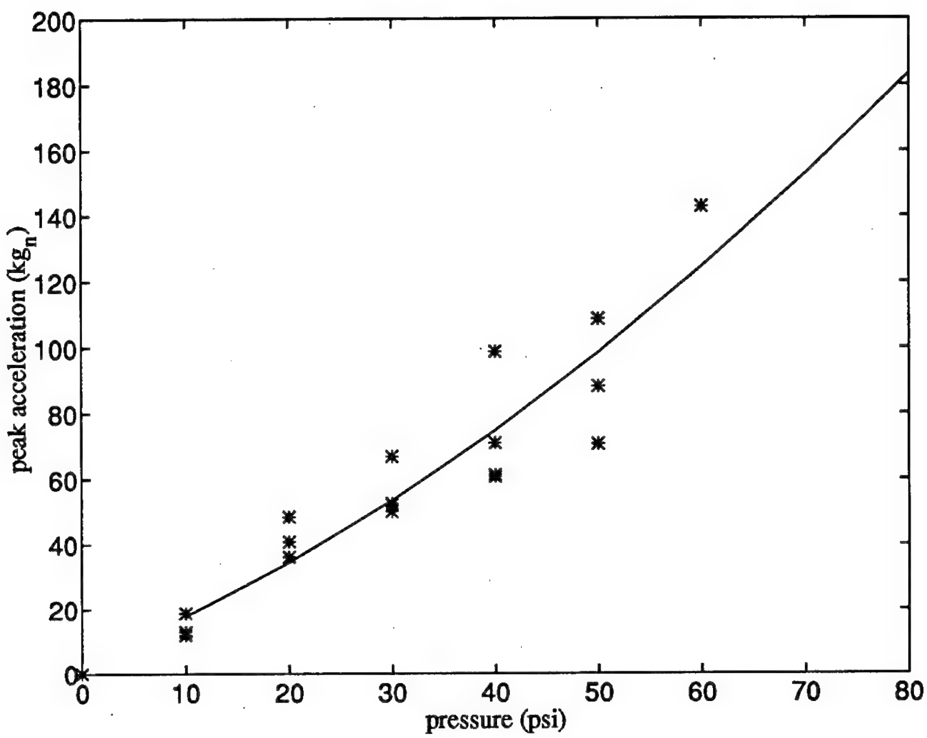

Figure 4. Calibration curve for the 5 lb payload with no mitigator in place. The solid line is a quadratic fit and is extrapolated to the maximal operating pressure to guide in estimating the potential shock level of the vhg tester.

Here again, no test was conducted for pressure above 60 psi. Note that the Endevco Model 7270A 200k was permanently damaged during the test conducted at 60 psi though the shock intensity was no more than 145 kg_n.

3.2.3 Calibration for a 10 lb payload and a cardboard mitigator

In an attempt to eliminate some of the high frequencies that set the sensor into resonance, a series of tests was performed with a cardboard mitigator between the piston and the anvil. It was expected that this mitigator, by eliminating the metal-on-metal impact, would diminish the ringing of the sensor. The cardboard used was taken from the

back of a writing pad and had an average thickness of 0.70 mm before impact and of 0.052 mm after compression.

Effectively, the presence of a mitigator allowed the test to be conducted at higher pressure without damaging the sensor, but unfortunately the filtering effect of the mitigator also affected the 100 kHz frequency content of the shock pulse resulting in a smaller calibration curve as seen in Figure 5. The effect of the mitigator on the frequency content of the shock pulse will be discussed in details later.

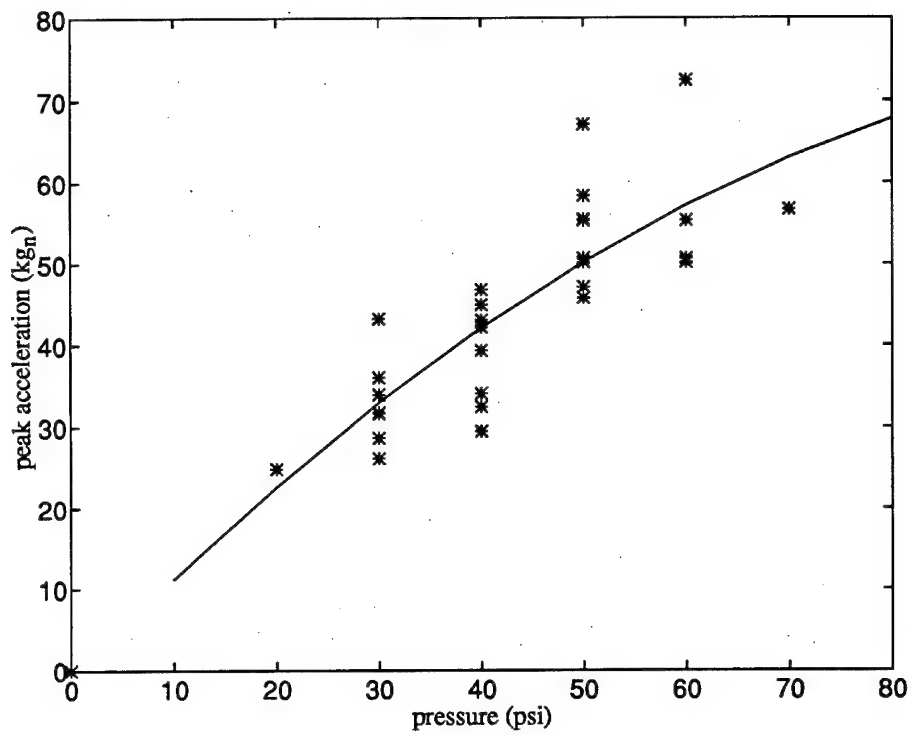

Figure 5. Calibration curve for a 10 lb payload when a cardboard mitigator is inserted between the piston and the anvil. The solid line is a quadratic fit.

3.2.4 Calibration for a 5 lb payload and a cardboard mitigator

Finally a few tests were done for this case and the presence of the mitigator yields the same effect as already discussed. The calibration curve for this case can be obtained from Fig. 6.

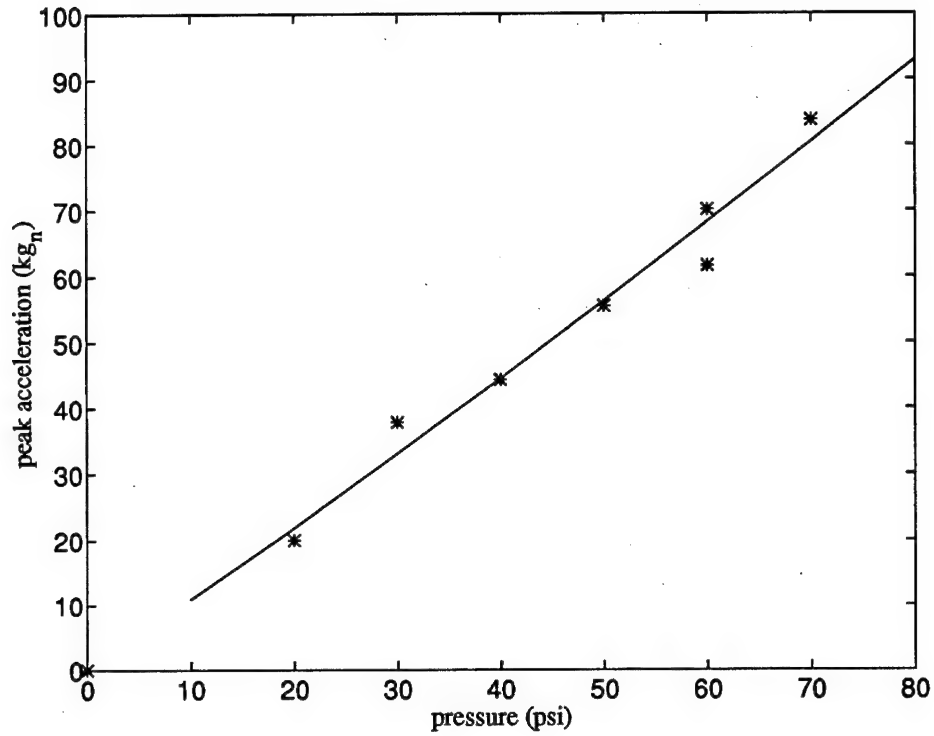

Figure 6. Calibration curve for a 5 lb payload when a cardboard mitigator is used. The solid line is a quadratic fit to the data.

3.2.5 Payload and mitigator effects

The calibration given in the previous sub-sections are limited to payloads of 5 and 10 lb and to only one type of mitigator. A brief discussion of the effect of the payload weight and the selection of a mitigator is at this time required. What is the calibration when testing a device on the vhg tester which weight is not 5 or 10 lb? It will be shown that an estimate of the operating pressure required for a desired shock level can be easily calculated. On the other hand, can different materials be used as a mitigator and how should they be selected? General rules in selecting a mitigator will be given.

In practical application, the device to be tested (ex: a fuze, a recorder, etc.) will weight somewhere between 0 to 10 lb and the question arises as which pressure should be selected to obtain the desired shock level. Two approaches can be used. First, ballast weights can be added to the set-up to reach one of the two weights used in the calibration. This allows to obtain the pressure straight from the calibration curve but complicates the set-up. Another approach not involving more weight but rather a simple calculation is obtained from Newton's second law. Since for a given pressure, the force transmitted to the anvil is in a first approximation always the same, the acceleration is then just a function of the total weight of the test carriage, the shock absorber and the test device. After some

manipulation, it can be shown that the expected peak acceleration "a(P)" at a pressure "P" for a test device of weigh "m" is given by

$$a(P) = \frac{33.5}{23.5 + m} a_{10}(P)$$

where $a_{10}(P)$ is the peak acceleration (in g_n) for the 10 lb payload at pressure (P) (in psi) from the calibration curve, and m is the weight in pounds of the test device. This equation gives the expected peak acceleration a(P) in g_n.

As an example lets assume that a 5 lb device is to be tested at 75 kg_n. By inverting the above equation the question becomes; "Which pressure is required to shock a 10 lb payload at 63.8 kg_n? From the quadratic fit of Fig. 3, the answer is 40.2 psi while the fit of the experimental data for a 5 lb payload in Fig. 4 yields a value of 40 psi.

Of course it will always be necessary to instrument the test with an accelerometer if a precise knowledge of the shock level is required simply because of the strong dispersion in the calibration data points. This simple approach is adequate if an approximate shock level is acceptable or as a starting point for the first run.

The effect of the mitigator is clearly to remove or decrease some high frequencies component in the shock pulse. It acts as a mechanical filtered and helps in protecting the accelerometer from entering into resonance. The choice of a mitigator requires a data base of test results which is not available for the vhg tester. Nonetheless some basic rules can be keep in mind.

One of these rules is the thickness of the mitigator. The thicker the mitigator the more the high frequency component will be filtered away. Unfortunately this will also affect the lower end of the frequency spectrum and therefore decrease the overall shock level. The hardness of the mitigator is also a factor. As a rule of thumb, the harder the material the higher the cut-off frequency.

It is important to realize that the mitigator must be place under the anvil if the accelerometer reading is to be related to the test carriage acceleration. This is mainly because most mechanical filters are not linear. One should also note that in using a mitigator, it should be impacted to a high level shock before taking measurement. This compression will ensure repeatable results.

3.3 Acceleration pulse duration

The peak acceleration is a valid parameter in the calibration of an impact tester but too often is given as the only parameter which leads to incomplete and even erroneous interpretation of the apparatus performance. For example most electronic components will survive a 100 kg_n acceleration in a centrifuge but will be permanently damaged under

a 50 kg_n shock created by a metal-on-metal impact. One important difference between the two shocks is the frequency content which can roughly be represented by the pulse duration. In the case of a centrifuge, there is very little high frequency as this level of acceleration is reached over a relative long period of time, while in a metal-on-metal impact the peak acceleration is reached within a few microseconds yielding an acceleration pulse with an important high frequency content.

The acceleration pulse duration for the tests performed on the vhg tester were measured from the 100 kHz low-pass filtered data and determined as the width at mid-height. For the limited data points available, it is observed that within measurement error the pulse width is independent of the operating pressure but is a function of the payload.

The results show that for a 10 lb payload with no mitigator in place, the pulse duration is 49.2 ± 5.8 µsec. The average was done over operating pressure ranging from 10 to 60 psi. In the same way, 63.7 ± 4.3 µsec is the observed average acceleration pulse duration for a 5 lb payload when no mitigator is used.

If a mitigator is in place, the pulse width is expected to increase as the amplitude of the shock decreases. A very small increase in the pulse duration was observed when the thin cardboard mitigator was used. For a 10 lb payload with a cardboard mitigator, the average pulse duration is 50.1 ± 8.7 µsec and it is 65.5 ± 15.0 µsec for a 5 lb payload.

A longer duration acceleration pulse can be achieved by using a thicker mitigator (many cardboard layers, rubber, etc.). Of course using thicker layer of a soft mitigator like cardboard will lower the intensity of the shock. It is believed that a 100 kg_n peak acceleration pulse with a 80 µsec duration could be achieved at the maximal operating pressure of 80 psi. This has not been demonstrated though.

4. FREQUENCY ANALYSIS AND DATA REDUCTION

Often, a shock measurement in the form of a time-history of a motion is of limited use for engineering purposes. Reduction to a different form is then necessary, the type of data reduction employed depends upon the ultimate use of the data. In this sub-section, three forms of data reduction will be briefly covered; power spectrum, transfer function and shock spectrum. Each will bring out a different aspect of the vhg tester.

4.1 Frequency analysis

Fourier transforms allow visualization of the frequency content of a signal and permit an easy identification of important frequency components. A conventional application of the Fourier transforms is the power spectrum analysis. This approach was used on the vhg tester results to track the accelerometer resonance. Figure 7 gives the results of the power spectrum obtained from a Fast Fourier Transform (FFT) for four

different operating pressures when a 5 lb payload was used with no mitigator in place. The accelerometer for that series of tests was an Endevco 7270A-200k which is specified to have a 1.2 MHz resonance frequency. This resonance frequency is clearly seen in the frequency spectrum. The average measured value for this frequency is 1.18 MHz in very good agreement with the manufacturer. Another important frequency component is observed at about 900 kHz which origin is at this time uncertain.

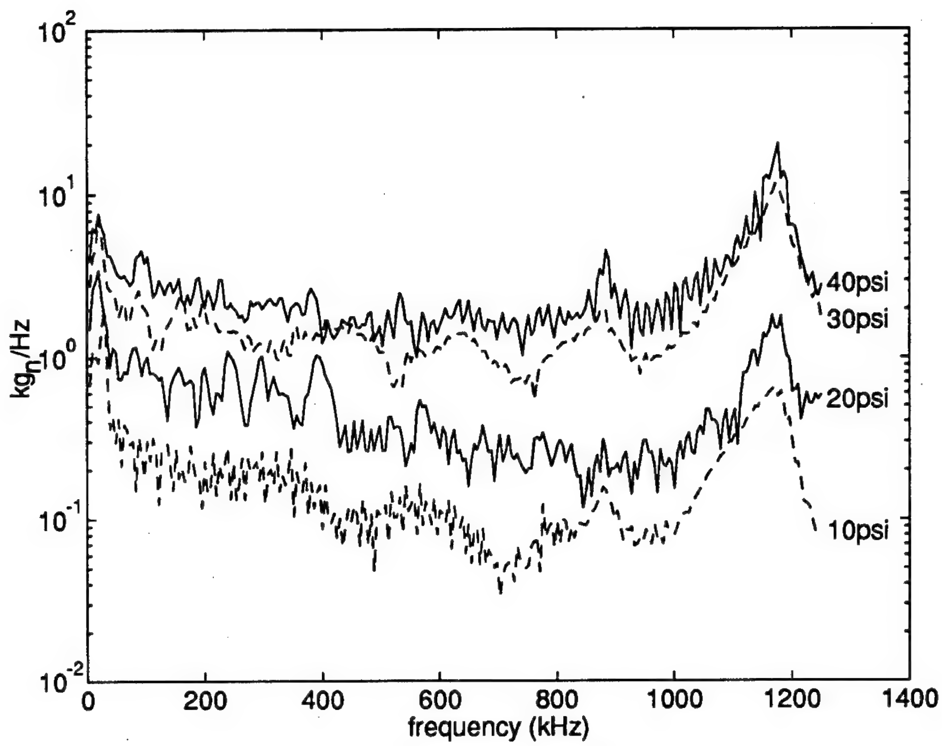

Figure 7. Power spectrum of the acceleration generated by the vhg tester with a 5 lb payload and no mitigator. The operating pressures are shown.

The Endevco 7270A series of piezoresistive accelerometer are considered fragile in the sense that they can be damaged by a moderate shock amplitude with high frequency content. The increase of the resonance is a precursor to the accelerometer failure and can be monitored from the Fourier transform. When the resonance frequency component level of the Fourier transforms becomes higher than any other frequencies, as for the 30 and 40 psi shock in Fig. 7, the limit of the sensor is achieved. In the tests of Fig. 7, the accelerometer was permanently damaged on the next shock.

Another useful application of the Fourier transforms is the evaluation of the role of a mitigator. It was mentioned previously that a mitigator acts as a mechanical filter by attenuating the higher frequency component and therefore protecting the accelerometer from failure due to its resonance excitation. Figure 8 gives the power spectrum of the acceleration pulse for a 5 lb payload when the vhg tester was operated at 30 psi. The

results when no mitigator was in place and when a cardboard mitigator was used are given.

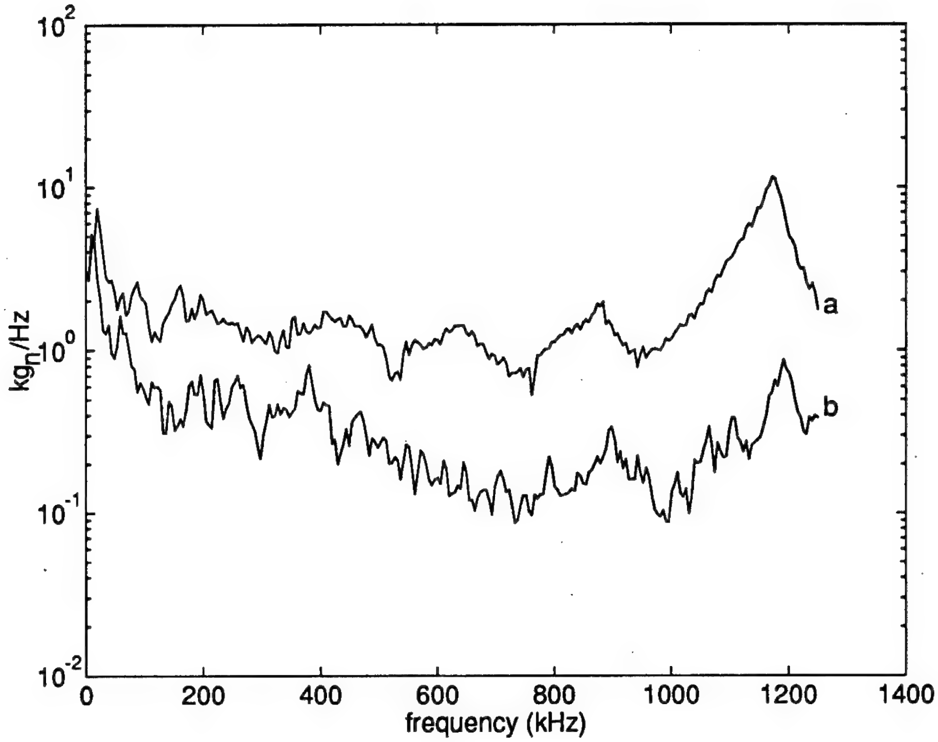

Figure 8. Power spectrum for a 5 lb payload and an operating pressure of 30 psi. a) with no mitigator (metal-on-metal impact), b) with a cardboard mitigator inserted between the piston and the anvil.

One must be aware in interpreting the data that the two tests of Fig. 8 are from tests conducted at two different times and that though the selected operating pressure was the same, the shock levels were different due to the strong dispersion in the data. Nonetheless, specific trends can be observed. The effects of the cardboard are minor in the low frequency regime but become important at higher frequencies. To roughly quantify the role of this mitigator, the transfer function is calculated on the initial acceleration pulse recorded.

The transfer function of the cardboard mitigator can be obtained by the following equations[3]

$$\mathcal{H}(\omega) = \frac{\mathcal{F}[a_f(t)]}{\mathcal{F}[a_u(t)]}$$

where $\mathcal{H}(\omega)$, $\mathcal{F}[]$, $a_f(t)$ and $a_u(t)$ are the transfer function, the Fourier transform operator, the mechanically filtered acceleration and the unfiltered (no mitigator) acceleration trace. The frequency response of the mitigator are given as follows

$$g(\omega) = |\mathcal{H}(\omega)|$$

$$\phi(\omega) = \arg|\mathcal{H}(\omega)|$$

where $g(\omega)$ and $\phi(\omega)$ are the gain characteristics and the phase characteristics, respectively.

Figure 9 displays the gain calculated in this way. The effect of the mitigator is negligible below 20 kHz and on average the presence of the mitigator attenuates the amplitude of the frequencies higher than 20 kHz. Some structures are seen at 30 kHz and 50 kHz on which no attempt to understand their origins have been performed. Overall, it appears that the cardboard mitigator acts as a low-pass filter which attenuates the 1.2 MHz resonance frequency amplitude by about 15 decibels.

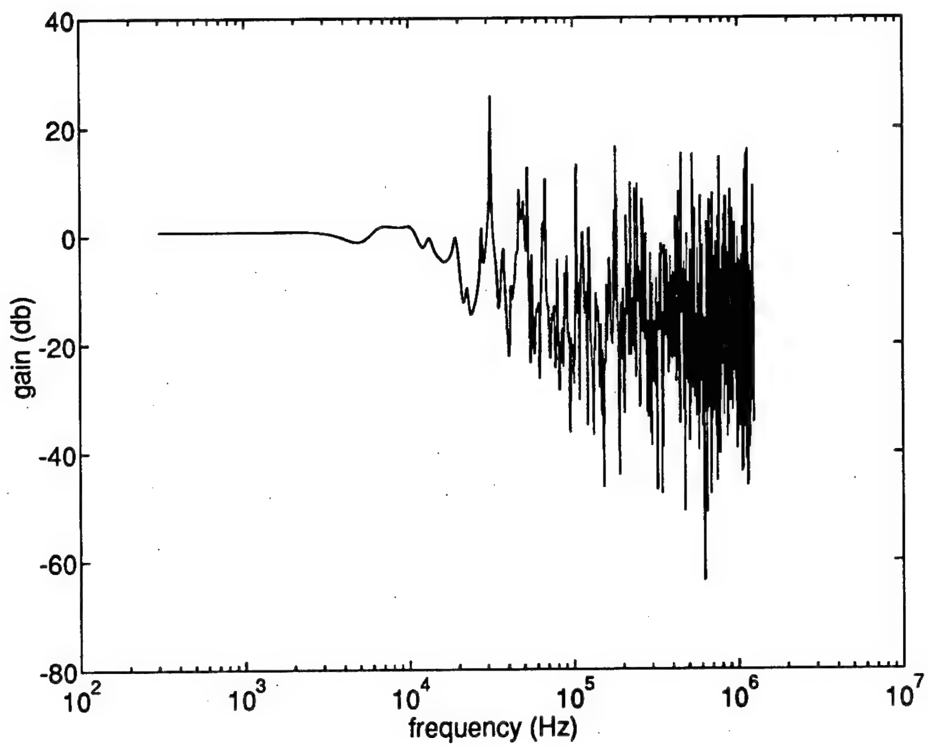

Figure 9. Gain characteristics of the frequency function displaying the effect of the cardboard mitigator on the frequency content on the acceleration pulse generated by the vhg tester.

4.2 Shock spectrum

Finally, the shock spectrum is calculated for the vhg tester and compared with a typical shock encountered in hard target penetration by a kinetic energy penetrator. The relative displacement response of a simple structure resulting from a shock defined by the acceleration $a(t)$ is given by the integral

$$\delta(t) = \frac{1}{\omega_d} \int_0^t a(t_v) e^{-\zeta\omega_n(t-t_v)} \sin \omega_d (t - t_v) dt_v$$

where ω_n is the undamped natural frequency, z is the fraction of critical damping and $w_d = w_n(1-z^2)^{1/2}$ is the damped natural frequency. The acceleration $a(t_v)$ is defined as a function of the variable of integration t_v and the response $\delta(t)$ is a function of time t. The relative displacement δ and the relative velocity $\dot{\delta}$ are considered to be zero at t = 0. The equivalent static acceleration A_{eq} is

$$A_{eq}(\omega_n, \zeta) = w_n^2 \delta_{max}(\omega_n, \zeta).$$

The equivalent static acceleration is the steadily applied acceleration which would distort the structure to the maximum distortion resulting from the action of the shock for that specific frequency. A physical system like an accelerometer (and its mount) has a characteristic response when a shock is applied as an excitation to the structure. The magnitudes of the response peak can be used to relate the peak response to the properties of the system and to compare different systems. This is different than a Fourier transform, whereas the Fourier transform defines the shock in terms of the amplitudes and phase relation of its frequency content components, the shock spectrum describes only the effect of the shock upon the structure in terms of peak responses. In the shock spectrum, only the maximum value of the response found in a single time history is plotted for each frequency.

Figure 10 gives the shock spectrum for the most severe shock generated on the vhg tester without damaging the hard mounted accelerometer. Also displayed in this figure is the shock spectrum of a deceleration trace obtained from a kinetic energy penetrator perforating a concrete slab. This second curve gives an estimate of the acceleration level as a function of frequency that can be encountered by the component of a hard target electronic fuzes. The frequencies were cut off at 100 kHz since the recorded acceleration in the concrete penetration utilized a recorder with a 100 kHz low-pass filter.

It is interesting to note that the vhg tester can impart shock more severe than the selected field test for the range exceeding 25 kHz. For the lower frequency range, the vhg tester does not generate a long enough pulse duration to adequately reproduce the field test.

From the result of this shock spectrum, it can be seen that on a first approximation, the vhg tester is a valid instrument to qualify and even quantify hard target fuze components behavior in the higher frequency range but is inadequate to perform reliable evaluation below 25 kHz.

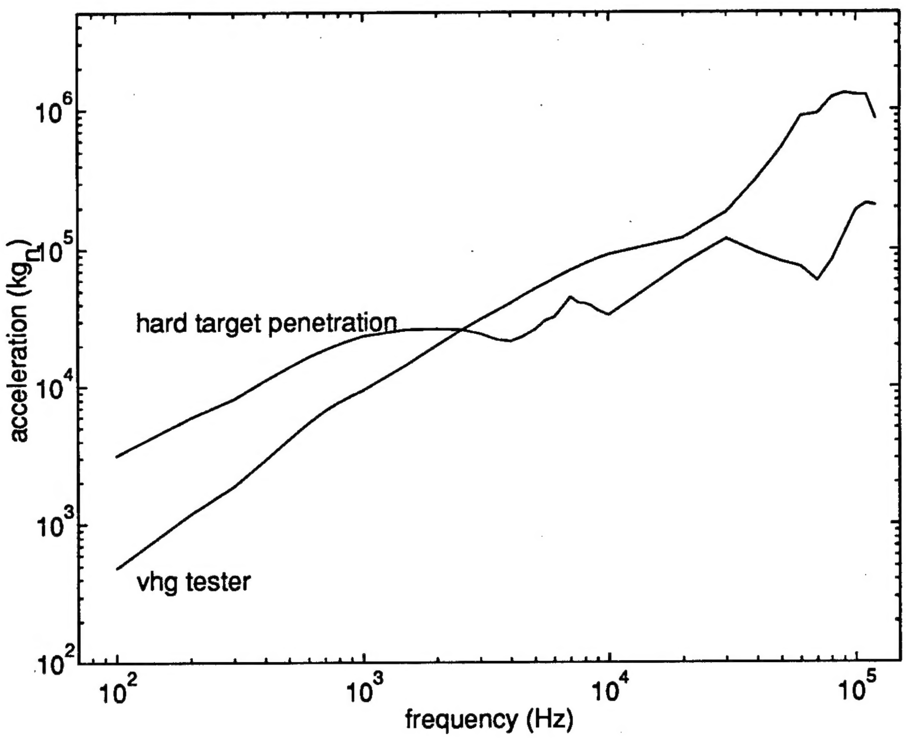

Figure 10. Shock spectrum for the most severe measured shock on the vhg tester and for the measured deceleration profile of a 30 lb kinetic energy penetrator perforating a concrete slab at 300 m/s.

Note that the hard target penetration shock spectrum was obtained from a specific field test where a 30 lb penetrator was launched against a concrete slab at velocities of about 300 m/s. A different warhead would generate a different shock spectrum. As an example a large penetrator would have a shock spectrum with less amplitude while a smaller one would be subjected to a higher deceleration and therefore would have a higher amplitude.

The shock spectrum is therefore a valuable guide in determining the extent tests performed on the vhg tester are a representation of the actual shock level and duration encountered in an actual field test.

5. CONCLUSION

The calibration and characterization of the WL/MNMF vhg were conducted to evaluate its range of application and to quantify its performance. This tester was designed to produce severe shock and allow the testing in a controlled shock environment of a whole fuze or fuze components.

The calibration was defined as the peak acceleration of the 100 kHz low-pass filtered acceleration pulse measured by an Endevco 7270A piezoresistive accelerometer during impact. It was correlated to the operating pressure. Peak accelerations up to 120 kg_n were measured at pressure below the limit of the vhg tester. Therefore higher values can be reached but couldn't be monitored by the selected accelerometers. Further investigations are required to determine if the important dispersion observed in the calibration data can be reduced. It is recommended that further investigations be conducted to reduce this scattering. A better control of the operating pressure and a reduction in piston friction in the gun barrel would definitively improve the scattering problem.

The role of a cardboard mitigator between the piston and the anvil has been determined and quantified. It basically acts as a low-pass mechanical filter with a cut-off frequency of about 20 kHz and attenuates the 1.2 MHz resonance amplitude of the accelerometer by roughly 15 decibels. It is recommended that this mitigator and other mechanical filters be tested and their linearity determined.

The evaluation of the shock spectrum from the vhg tester and a comparison with the shock spectrum of a recorded deceleration during concrete penetration by a warhead, give the range where the shocks generated by the vhg tester are equal or exceed those encountered in field tests. It has been shown that the vhg tester is a valid tool for testing the performance of a system under shock for frequencies above 25 kHz but there is not enough energy in the pressure chamber to simulate the lower end of the spectrum.

Overall the vhg tester is a valuable instrument for conducting inexpensive tests on the behavior of any system weighting less than 10 lb under very high accelerations.

6. REFERENCES

1. DeVost, V.F., "Vhg IMPACT TEST SET", NOLTR 68-158, September 68

2. User Manual, "IES Model 32 Recorder", Instrumentation and Engineering Services Inc., Fort Walton Beach Fl 32549.

3. Ueda, K. and Umeda, A., "Application of Davies' bar technique to the characterization of shock accelerometer", Proc. 9th Int. Conference on Exp. Mech., 261-270 (1990).

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